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Research Note (Subject – Geophysics)

Seismic Sequences of Odun Field, Niger Delta: Derivation of Stratigraphic and Structural Settings

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Abstract

The Tertiary Niger delta basin is one of the most prolific and economic sedimentary basins in Nigeria by virtue of its significant amount of accumulations of hydrocarbons. The basin has remarkably maintained a thick sedimentary apron and other geological features favourable for hydrocarbon accumulation. The geological features containing stratigraphic, structural and sedimentological information can be studied using seismic data by means of seismic sequence and its facies analysis.

Geological features identified in studied seismic sections include channel fills, slumped deposits, shale diapirs and faults. The most prominent structural feature in studied seismic sections is the zone of shale diapirism, in seismic sequence Q, which spans across the study area with the uplift high at the western end through to the central part of the field and flattening towards the eastern part of the field. The seismic sequences L, K and J contain numerous faults. These faulted zones lie within reflection time zones which are equivalent to 1300 m to 2040 m in depth. These L, K and J sequences contain alternations of shale and sandstone. Seismic sequences N, O, and P are predominantly sandy in composition. The lower part of seismic sequence D is shaly which is grading to sandstone towards upper part. The upper most seismic sequences A, B, and C are predominantly sandy. Studied and provided information can be gainfully utilized, integrating more data from the region, to explore new zones of hydrocarbons in nearby regions.

Keywords: Seismic sequence, Facies, Stratigraphy, Structural, Odun field, Niger delta, Nigeria.

Introduction

The concepts of depositional history, episodes and settings from seismic stratigraphy have been developed to analyze and interpret thick basin fills. The method which was developed by early workers (Vail *et al*, 1977; Mitchum, 1985) was based on the recognition of unconformities and reflection patterns on seismic data. Reflection terminations interpreted as strata terminations include erosional truncation, toplap, downlap and clinoform.

The Niger delta is generally agreed to be built on an oceanic crust. Supporting arguments arise from the pre-continental drift fitting which indicate an overlap of Northeast Brazil on the modern day Niger delta, and the presence of a series of linear subdued and alternatively positive and negative

anomalies beneath the Niger delta sedimentary basin (Burke et al, 1972). These laid a foundation for the sedimentary aprons occurring in the modern Niger delta. These sedimentary units are deformed by syn-sedimentary faulting and folding (Weber and Daukoru, 1975). The processes and mechanisms involved in this deformation are still being discussed.

Recent intensive studies including geophysical methods have been used to study the Niger Delta and more findings and suggestion have been put in place. Further studies on seismic data and well log data have been carried out by more recent workers, utilizing 3D seismic structural and stratigraphic interpretation, reservoir characterization and volumetric studies, coupled with sequence stratigraphy studies, over several fields in the Niger Delta basin. Some of the earlier works can be found in; Adeoye and Enikanselu (2009), Edigbue et al. (2014) and Omoboriowo et al. (2012). The objective of this study is to decipher depositional settings and structural aspects of the Odun field, Niger delta using available seismic and well log data.

Location of Study Area and General Geology

The study area is a field situated in OML-X, Offshore southwestern part of the Niger delta in the Gulf of Guinea (Fig. 1). It lies in a water depth range of 100-350 m.

The Niger delta complex covers a land area in excess of 105, 000 km^2 (Avbovbo, 1978) with a sediment thickness of about 12 km at the central part (Reijers *et al.*, 1997). It extends in an East-West direction from southwest Cameroun to the Okitipupa Ridge.The Niger-Benue and Cross River systems, together with other distributaries, serve as the source of the sediment fills in the present day Niger delta. These fills comprise unconsolidated sands and overpressured shales. The Formations in the Tertiary Niger delta include the Agbada and Benin Formations to the North with a transition to the Akata Formation in the deep water portion of the basin where the Agbada and Benin Formations thin and disappear seaward (Fig. 2).

The Niger delta continental shelf, in some places, is characterized by clay/shale diapirs and growth fault (Fig. 2). The presence of growth faults and associated rollover anticlines in most part of the sedimentary basin signifies that structural traps for petroleum is common in the Niger delta.

The Akata Formation is the basal sedimentary unit in the Niger delta province. The shale ranges from Paleocene to Holocene in age. It is a low plastic density, high pressure, shallow marine deep water shale Formation ranging in thickness from 2000-20,000 meters. In general, the Akata Formation is dark grey and crop out offshore along the continental slope and onshore in the northeastern part of the delta, where they are known as Imo shale. Except on the flanks, no well has fully penetrated this sequence.

The Agbada Formation which overlies the Akata Formation, consists of unconsolidated to slightly consolidated paralic siliciclastic sequence of sandy unit with minor shale intercalations of about 4500 m thick (Weber and Daukoru, 1975). These paralic sequences were deposited in a number of delta fronts and fluvio-deltaic environments. There is consistently an upward increase in the sand content in any given area. In the lower portion, shale and sandstone beds are deposited in equal proportion (50%), however, the upper section is mostly sand (75%) with minor shale intercalations. Its oldest units of sediments are Eocene in age and deposition continues to Recent.

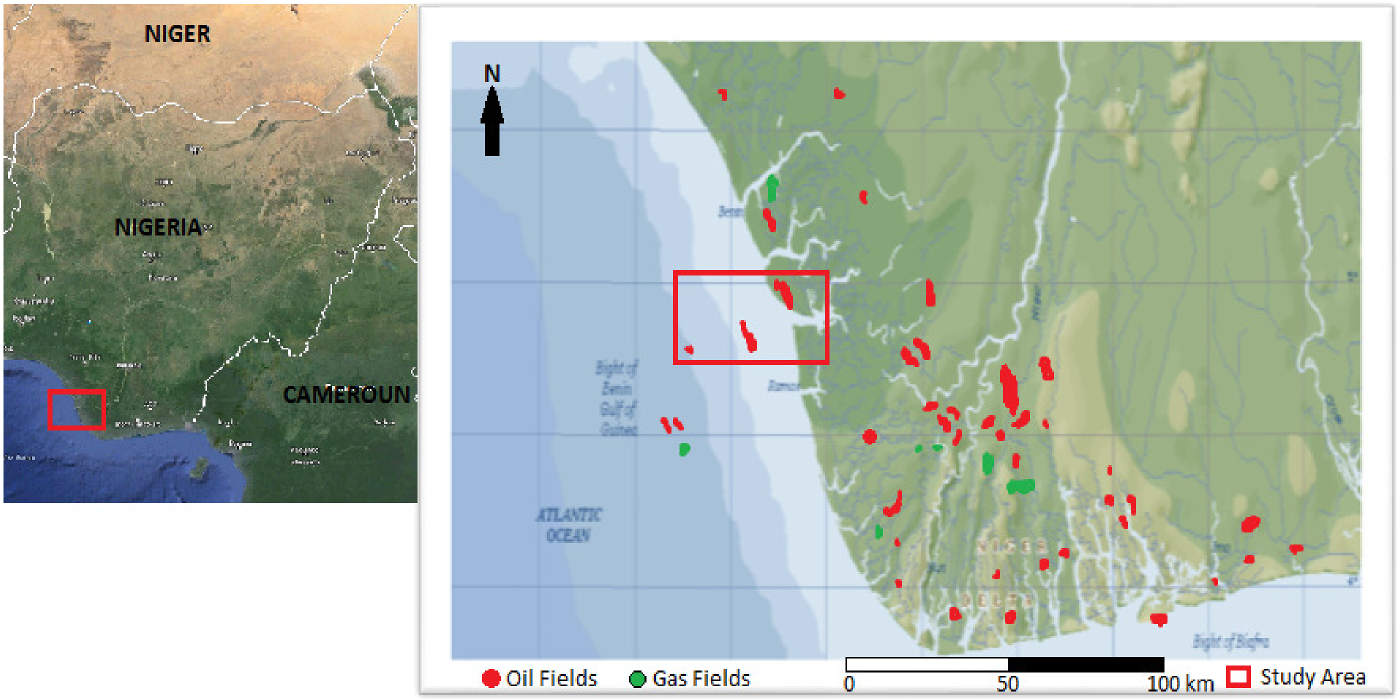

Fig. 1. Location map showing the study area and major oil and gas fields (Image courtesy of Google Earth).

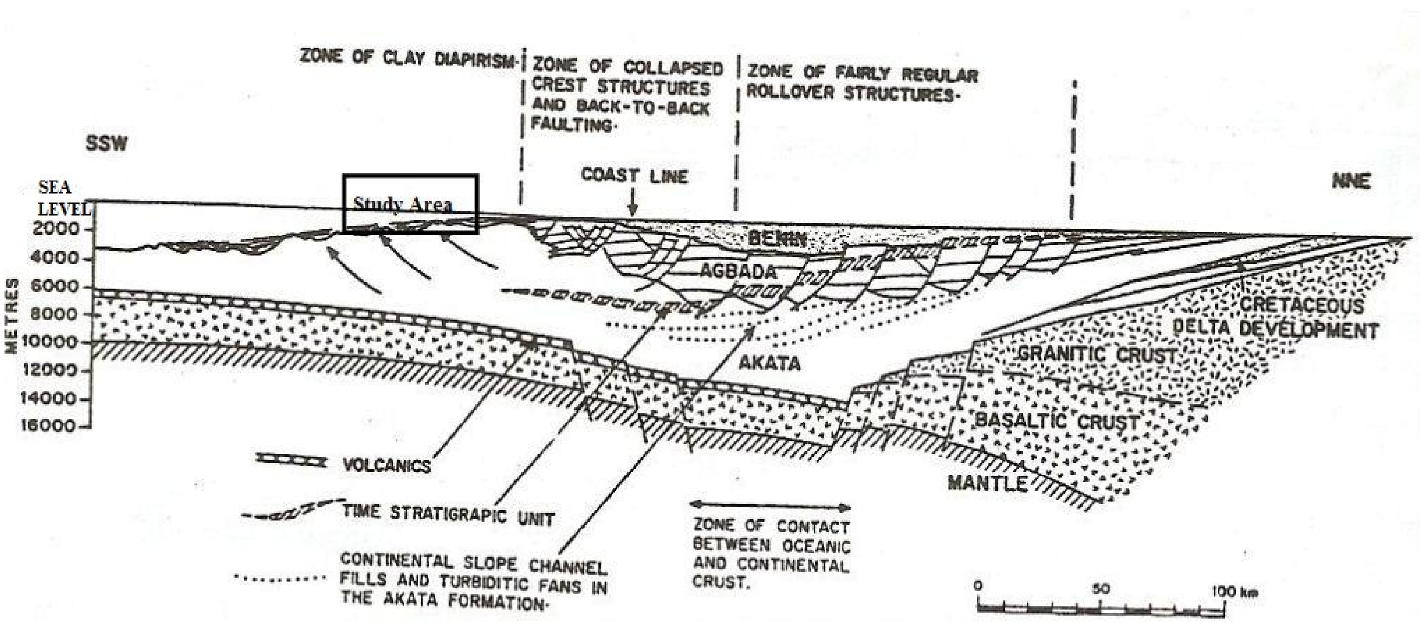

Fig. 2. Schematic dip section of the Niger delta (Modified from Weber and Daukoru, 1975).

The Benin Formation marks the uppermost unit of the Delta Complex, consisting mainly of 2000 m fresh water-bearing massive continental sands and gravels which are deposited in the Upper deltaic plain environment. Its occurrence spans the Benin-Onitsha area in the north to beyond the present

coastline (Short and Stauble, 1967). The Formation ranges in age from Oligocene to Recent.

Materials and Method

The datasets for the study are made up of digital suites of well logs, checkshot and 3D seismic (ZGY Format). The data is from a field which is referred to as Odun Field for the purpose of this study. The interpretation of this data has been achieved using the Schlumberger's PETREL 2010 version software.

Identification of seismic sequence was done after which the evaluation of associated facies proceeded. Seismic facies analysis, which is a geologic interpretation of seismic internal reflection patterns, was carried out. It involved the recognition of the seismic facies units, definition of their limits and mapping of their areal associations. They are interpreted to express certain stratification, lithologic and depositional features of the deposits that generated the reflections within the units. Seismic line terminations, geometries and configurations were interpreted as stratification patterns. These, in turn, aided the recognition of depositional sequences and interpretation of depositional environment. Inferred depositional sequences within the field have been labeled A-Q.

Gamma ray log were integrated to analyze and validate seismic facies. Vail and Wornardt (1991) used the log shapes, resulting from a combination of spontaneous potential or gamma ray log and resistivity to interpret the lithofacies and depositional systems in the Gulf of Mexico. Checkshot chart (Fig. 3) was used in simplifying reflection time – depth relationship, as seismic surfaces only represent surfaces of equal reflection time. This chart was derived using the available checkshot data for Odun XY01 well. Two-Way Time (TWT) is given in milliseconds (ms) while the true vertical well depth is given on the x-axis in meters (m).

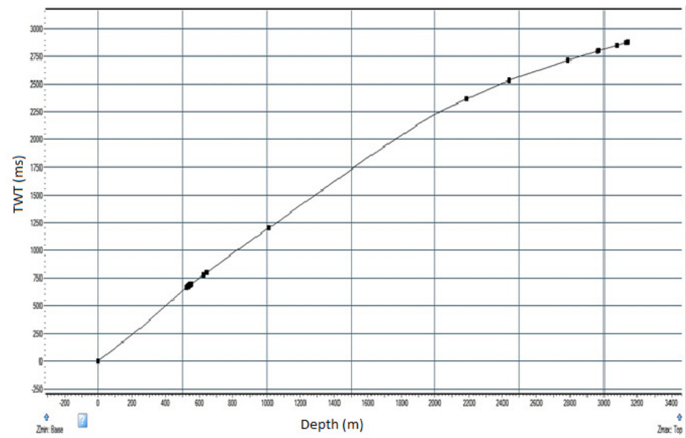

Fig. 3. Check-shot (TZ) Chart used for converting time to depth in the interpretations.

Results and Interpretation

Seismic sequences and their facies

Two seismic In-line sections were picked at strategic positions across the field in order to have a good idea of the fill history of the rock units present in the field. The seismic In-line sections include 13129 and 12849 seismic sections, located at western part and almost central part of the field respectively.

Seismic sequences were separated out based on changes in seismic lines acoustic impedance as each seismic line are time lines and it changes across unconformities or lithological boundaries. Seismic facies analysis was done by determining internal geometry, continuity, amplitude and other attributes of reflection characteristics within each seismic sequence. These were integrated, evaluated and corroborated further using gamma log data. These led to identification of seventeen (17) seismic sequences across the study area, with seismic sequence Q being the oldest while A is the youngest. These are described below:

Seismic Sequence Q

This occurs as an uplift with a characteristic chaotic reflection pattern composed of discontinuous and discordant reflections of variable amplitude and frequency (Fig. 4-7). This sequence spans across the field with the uplift high at the western end (Fig. 5) through to the central part of the study area and flattening towards the eastern part (Fig. 4-7).

These reflection characters suggest a highly disordered internal organization of the deposit. Features of this nature suggest slumped deposit on a slope, olistostromes, overpressured shales, volcanic rock, mobile salt deposits or salt pillows (Veeken, 2007). In this study, it is observed that the well shown is able to penetrate the pillow structure, hence it is interpreted as a shale ridge (Fig. 6 & 7). These were extruded in a seaward direction as a result of differential loading on the plastic marine shale (Hospers, 1971).

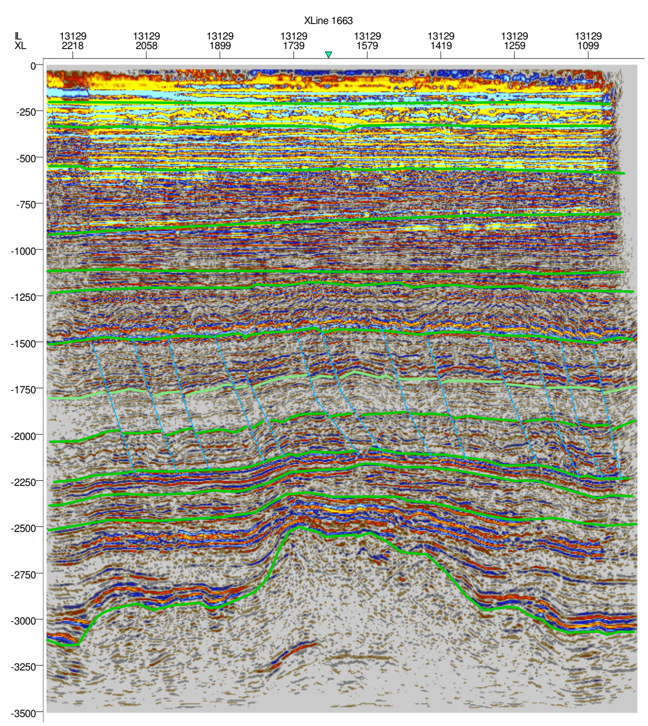

Fig. 4. Seismic stratigraphy interpretation of Inline-13129 seismic section.

Seismic Sequence P

This P seismic sequence is above Q and differentiated from below sequence by virtue of its recognizable reflection event and relatively continuous seismic lines (Fig. 6). This sequence exhibits relatively higher amplitude and continuous seismic lines.

Sequence P is interpreted as a sequence having a different lithology extended continuously in comparison to sequence Q. Gamma log evidence (Fig. 7) indicates that this sequence is predominantly sandy.

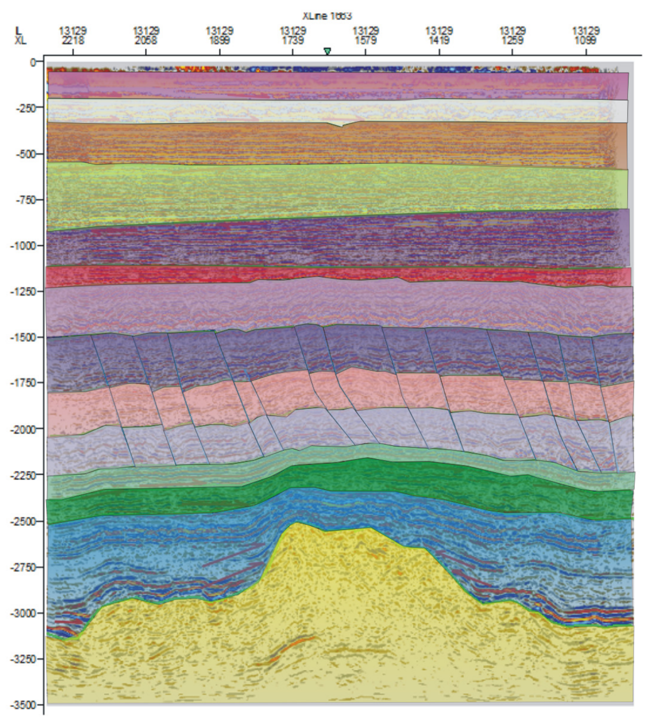

Fig. 5. 2D Model of seismic sequence and structural pattern of Inline-13129 seismic section.

Sequence Sequences O and N

Sequences O and N is above P. Seismic sequences O and N are characterized by relatively moderate seismic line continuity and low amplitude. Reflection package N is interpreted as a part of

sequence O because of the similar characteristics and properties

Gamma log curve shows that O and N seismic sequences are predominantly sandy. Mound features observed in the seismic reflection package labelled '**N**' indicate a higher energy environment in the basin. The zone containing the mound features is interpreted as slope channel fill. This is also confirmed by the expanded gamma ray log trend (Fig. 7). Sediments within this environment are usually characteristically poorly to very poorly sorted, with some gravel and clay pebbles. Slumped nature of part of the sands has also been recorded (Odundun, 2012).

Seismic Sequence M

The seismic sequence spans across the field and is located within the range of 2250 ms to 2350 ms reflection time which is equivalent to 2040 m to 2120 m in depth (Fig. 6 & 7)

The base is characterized by a surface of marine transgression. Lithological evidences from well log suggest an intercalation of sand and shale (Fig. 7).

Seismic Sequences L, K and J

These lie within the faulted zone and they span across the field lying within the range of 1500 ms to 2250 ms reflection time which is equivalent to 1300 m to 2040 m in depth.

These sequences contain thin litho-units of sand and shale which have been disrupted and truncated by faulting (Fig. 7). The growth fault structures unique to these sequences are rotational and are formed due to internal gravity tectonics. The rollover crests associated with these faults are well defined.

Seismic Sequence I

This sequence is differentiated by a characteristic change in facies as compared with the upper and lower sequences. The seismic sequence has a characteristic hummocky reflection configuration, high amplitude and frequency.

The sequence can be interpreted as a lithologic sequence whose litho units exhibit little systematic reflection termination indicating the presence of cut and fill geometries, which usually result from water escape during early burial and compaction. This sequence contains an intercalation of sandstone and claystone.

Seismic Sequence H

This sequence is bounded at the base by surface of marine transgression as it is evidenced from seismic and well log data (Fig. 6 & 7).

This sequence, with poor lithological contrast, poor continuity and thin-bedded litho-unit, shows a shale composition (Fig. 7).

Seismic Sequences G and F

The sequences, including the fill structure, lie within the time reflection range of 850 ms to 1100 ms which is equivalent to 700 m to 920 m in depth.

The fill structure was formed during deposition at this level, toward the central part of the field, as it does not extend toward the western part of the field in In-line 12849 seismic section (Fig. 6 and 7), and also fade away toward the eastern part of the field. This structure was formed due to the compaction of the underlying shale layer and as a result of subsequent deposition of overlying denser and thicker sand layers.

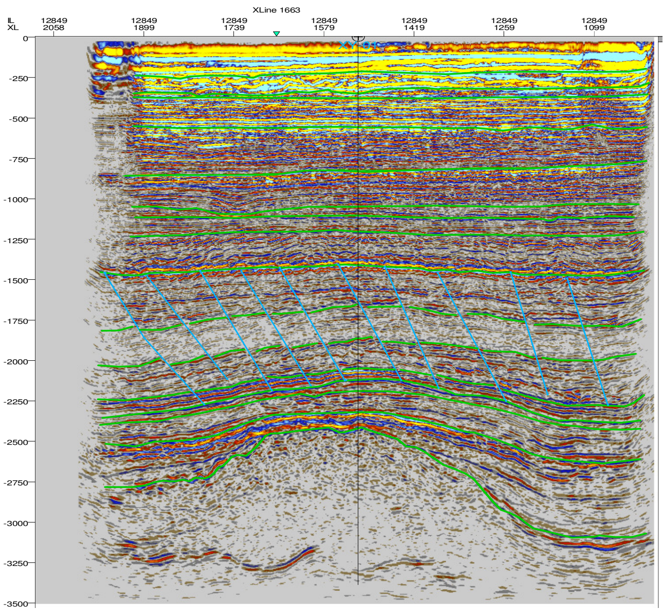

Fig. 6. Seismic stratigraphy interpretation of Inline-12849 seismic section.

Sequence E

The sequence spans across the field from west to east, but the blank anomaly of eastern seismic section hampers the sequence clear interpretation in the eastern part of the basin. Where observed, sequence **E** is characterized by high continuity, high amplitude and high frequency seismic facies with parallel reflection configuration.

The seismic lines configuration depicts sequence of high lithologic continuity, high lithologic contrast and thickly bedded litho-units which are closely packed and generally deposited at uniform rate on a uniform subsiding shelf or in a stable basin setting. The boundary represents the sharp deflection on the gamma ray log with a period of deposition of marine clay (Fig. 7).

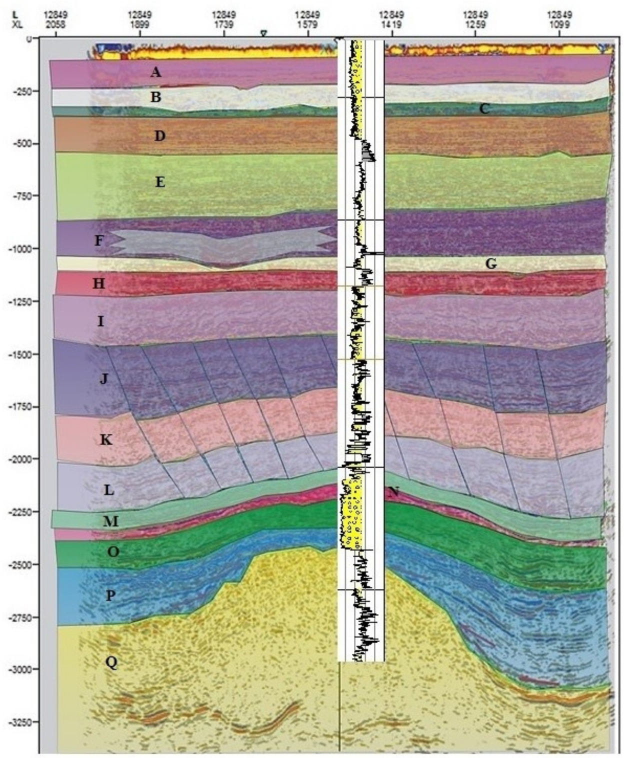

Fig. 7. 2D Model of seismic sequence, depositional pattern and lithology (from gamma ray log correlation) at Inline-12849 seismic section.

Sequence D

This seismic sequence has the following seismic line characteristics: high continuity, high amplitude, high frequency and parallel reflection configuration. The seismic sequence spans across the field at reflection time zone ranging from 350 ms to 550 ms which is equivalent to 240 m to 420 m in depth.

Seismic Sequence **D** has litho-units which are thick and closely packed. From the reflection configuration, sequence D can be interpreted as a sequence which has continuous and extensive lithologic units which are clearly separated into shale and sand on well log (Fig. 7). Figure 7 indicates that lower part of this seismic sequence is shaly and towards upper part it is becoming sandy.

Seismic Sequences B and C

These are said to be of the same reflection patterns as shown in figures 4, 6 and 7. The differentiated seismic sequence C at the same Inline-12849 has high amplitude, moderate to low reflection continuity (Fig. 6) while sequence B deposits is made of litho-unit of moderate continuity, high lithologic contrast and thick bed, which fade away toward the northeastern part of the field and toward the western and eastern part of the field (Fig. 4, 5 and 6).

The log signature indicates a coarsening upward deposit of sandstone (Fig. 7).

Seismic sequence A

The last sequence is delineated from the underlying sequence by a different reflection termination pattern. The seismic sequence lies within the reflection time of 0 ms to 250 ms which is equivalent to 0 m to 200 m in depth.

A gamma log curve indicates that the lithological composition of A seismic sequence is sandy (Fig. 7).

Conclusions

The seventeen (17) sequences were identified and marked on the seismic sections. The lower and older sequences are zones of rapid and gravity flow of materials. The structural settings of Odun field are characterized by systems of growth faults and rollover crests. Traps occurring in the study area are of both structural and stratigraphic types. Fault blocks and roll over crests are the structural traps while stratigraphic traps are mounds, slumps, shale ridges and divergent fills with overlying seals. All these may have created a good trapping system for the accumulation of hydrocarbon.

The Q seismic sequence is predominantly shale, as can be observed on log data. The shale ridge has been observed, in seismic sequence Q, as a zone of non-continuous and chaotic reflection patterns due to plastic deformation. The log data suggested thickly bedded and massive sandstones in seismic sequences N, O, and P. The seismic sequence L, K and J contains numerous faults. The lower part of seismic sequence D is shaly which is grading to sandstone towards upper part. The upper most seismic sequences A, B, and C are predominantly sandy.

Seismic stratigraphy technique has provided a clear view of the overall geological setup of the study area. This has also enabled us to derive the stratigraphic and structural information which can be gainfully utilized to infer new zones containing hydrocarbon in nearby regions.

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